Solidification Laboratory

Laboratory Coordinator: Dr. Arvind Kumar

Associated Faculty Members (if any):

List of Major Equipment:

- PIV system for melting/solidification studies for transparent metal analogue
- HS imaging camera
- Desktop computer workstations

Brief description of the laboratory:

Solidification Laboratory is involved in research on melting/solidification-based manufacturing processes. Cutting edge experimental and numerical research is performed in the areas of solidification processing namely casting, welding, metal additive manufacturing and thermal spray surface coating. The focus is on development of state-of-the-art computational models, controlled laboratory experiments as benchmarks and process development. Accurate models by comprehensively integrating the solidification thermodynamics with the attendant multiscale thermo-fluid phenomena have been developed for various solidification processes that can accurately predict and control the physical and metallurgical behaviour of solidification, defects and as-solidified microstructure. The other focus area of the lab is thermal energy storage using phase change material (PCM).

Laboratory research keywords:
Solidification; Casting; Laser welding; Transport phenomena; Segregation; Porosity; Multiscale modelling; Microstructure; Grain morphology; As-solidified material properties.

Major Research and Development Contribution of the Laboratory

Year	Major research and development activity
2020-2021	• Established the role of mushy zone flow instability on the formation of channels segregation during columnar solidification. Channel segregation defects are very critical for casting of structural steels, titanium and nickel based superalloys used in single-crystal turbine blades, aircrafts and nuclear reactors. ▪ Developed an experimental-numerical framework for additive manufacturing of aerospace component. Mitigated cracking in Laser Powder Bed Fusion (L-PBF) processing of Al7075 alloy powder by employing nanoparticle reinforcement and base plate heating. ▪ Developed a predictive numerical tool for thermal spray surface coating. Also developed HS in-situ imaging facility for droplet impact and solidification on surfaces.
2019-2020	▪ Developed open source software for modelling melting/solidification in metal alloys that incorporates the multiscale transport phenomena. ▪ Developed PIV and HS in-situ imaging facility for solidification of

	transparent metal analogues. Local and whole field imaging and measurement of temperature, flow, concentration, dendrite growth and dendrite fragmentation during solidification are possible. ▪ Developed predictive capability for metal additive manufacturing processes namely Laser Powder Bed Fusion (L-PBF) and Laser Directed Energy Deposition (L-DED). The predictive tool incorporates particle-scale modelling by coupling the optical and the thermo-hydrodynamical phenomena. ▪ Developed physics-based predictive capability for laser beam welding. Simulation and prediction of weldpool phenomena including weld composition.
2018-2019	▪ Established the effect of volumetric laser energy absorption on thermal-fluidic transport in powder bed fusion (PBF) based metal additive manufacturing of Ti6Al4V. ▪ Established the pore formation mechanism in thermal spray coating process by investigating dynamics of air entrapment. ▪ Developed numerical tool for thermal energy storage system. Simulation and prediction of cold energy storage (using ice slurry) and heat storage (using phase change material - PCM) parameters. ▪ Developed in-situ experiments to study the discharge stage in PCM.
2017-2018	▪ Developed predictive macroscopic modelling and simulation of laser spot welding process. ▪ Established discrepancy between numerical and experimental results for PCM based thermal storage and evaluated nano-enhanced composite phase change materials for waste heat recovery. ▪ Developed macroscopic models in OpenFOAM for directed energy deposition (DED) and powder bed fusion (PBF) based metal additive manufacturing . ▪ Understanding of thermal stresses in metal additive manufacturing is developed through track-scale simulations.
2016-2017	▪ Developed predictive capability of thermal field and weld bead characteristics in submerged arc welding. ▪ For better accuracy in predictions in thermal spray coating application, the rapid solidification and the undercooling effect have been coupled with the model of metal droplet impact and flattening on a substrate.
2015-2016	▪ Established the role of substrate melting and re-solidification in thermal spray coating process. ▪ For cold thermal storage using ice slurry, a numerical tool is developed to study the transport phenomena of ice slurry in an ice forming unit.

solidification in transparent analogues.

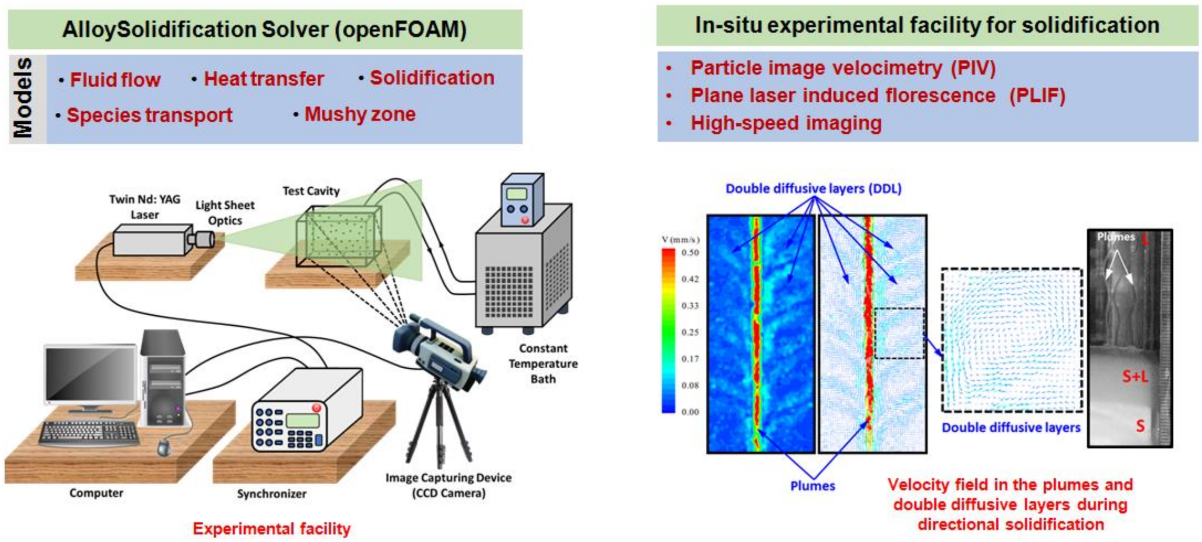

Figure 1: Opensource AlloySolidification software, and in-situ PIV, PLIF and imaging facility to investigate

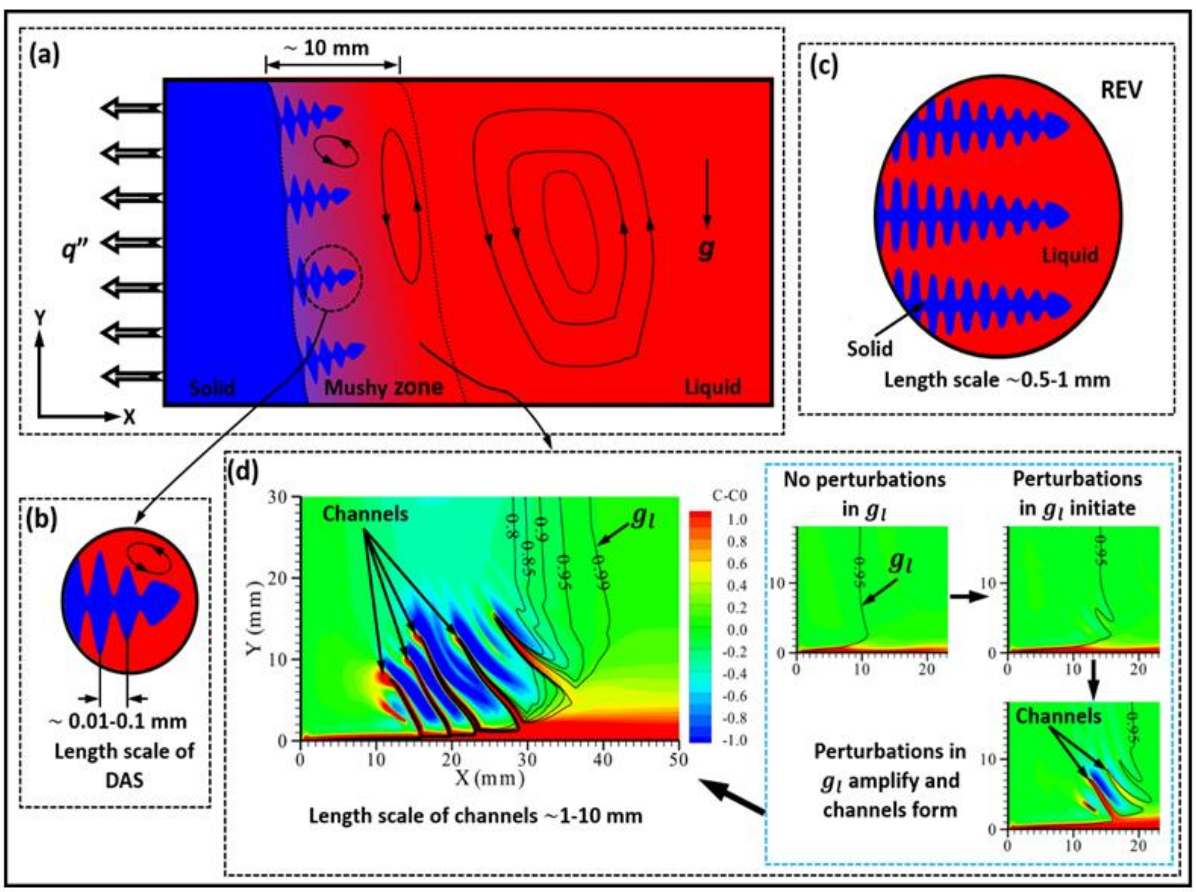

Figure 2: Illustration of the physical scales and the formation of channel segregates phenomenon during columnar solidification (a) system (macroscopic) scale, (b) grain scale, (c) representative elementary volume (REV), (d) formation of channel segregates.

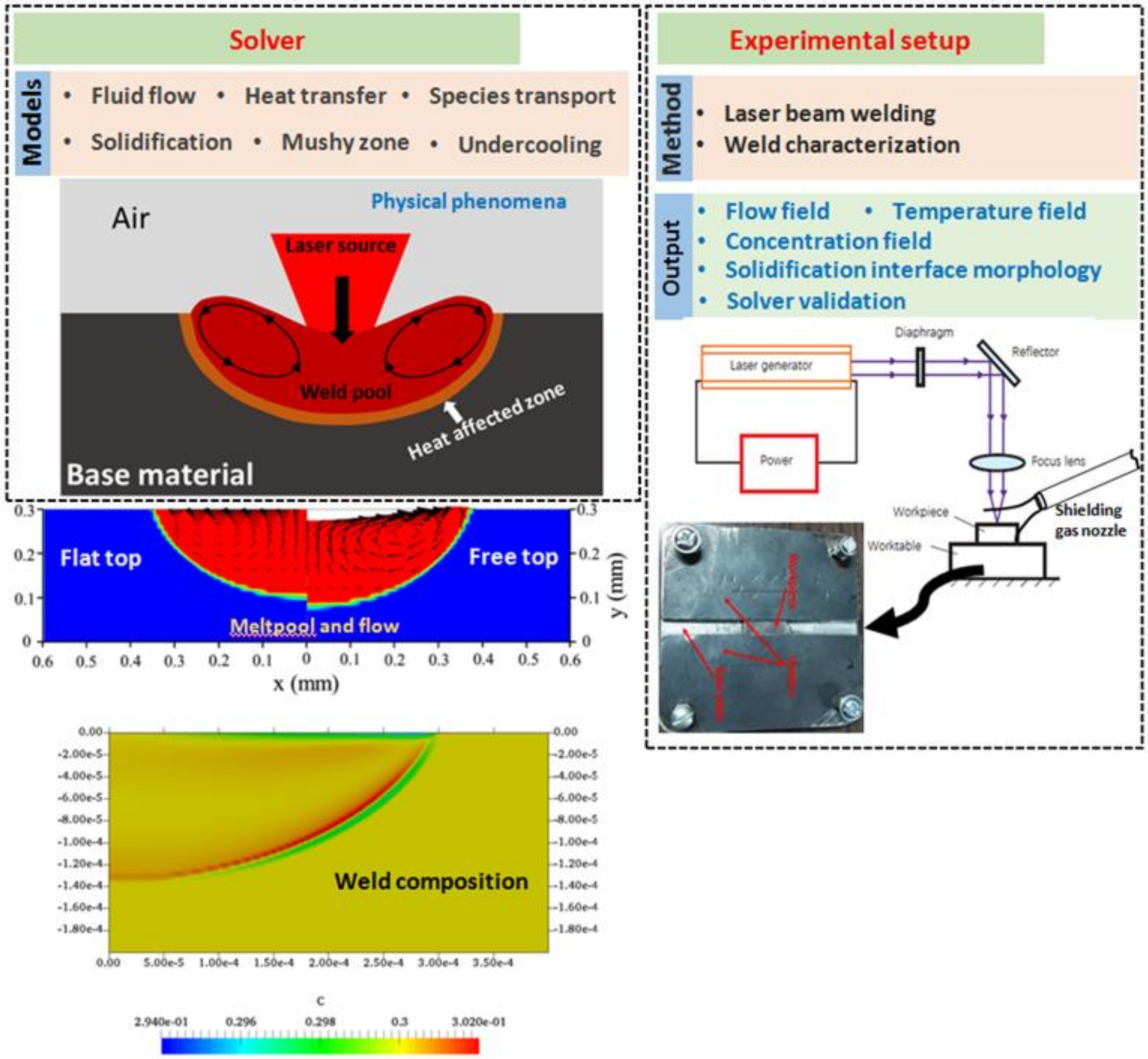

Figure 3: Software tool for laser welding and experimental setup.

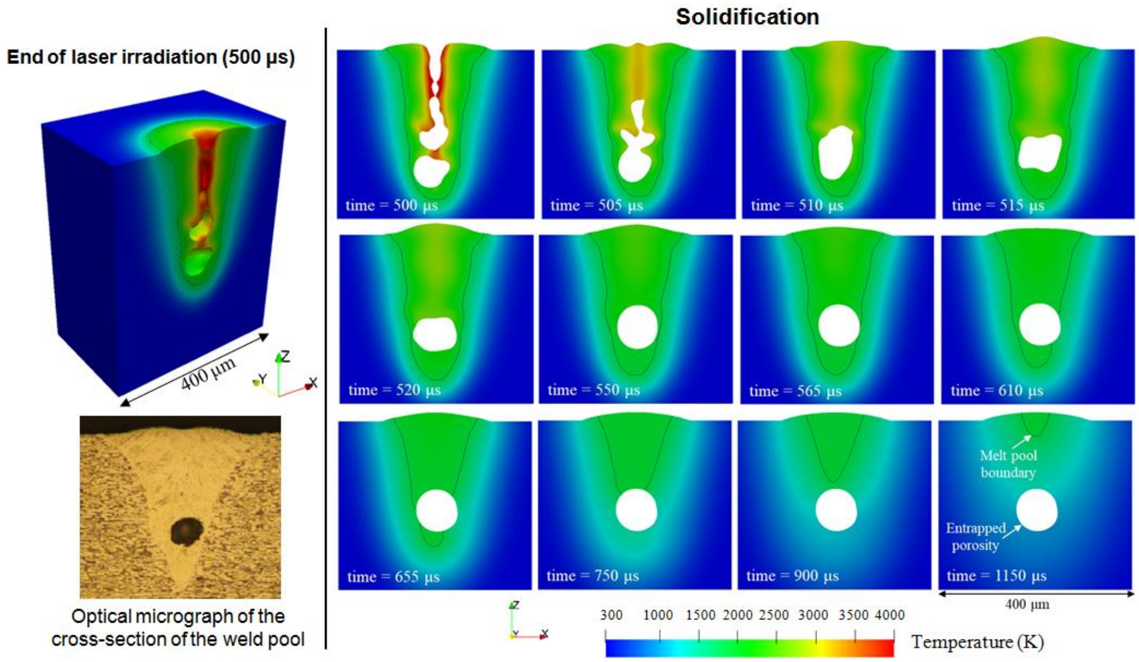

Figure 4: Trapping of gas cavity and residual porosity formation during stationary laser irradiation of Ti6Al4V. Laser power = 150 W, Beam diameter = 40 µm and Exposure time = 500 µs. Top image at left: at the end of laser exposure. Right images: meltpool and gas cavity dynamics during cooling. Left bottom: as-solidified weld pool. As the gas cavity is very close to the solidification front, it gets captured (610 µs) by the solidifying weld pool front resulting in the formation of a residual porosity (1150 µs). Such porosities degrade the weld quality.

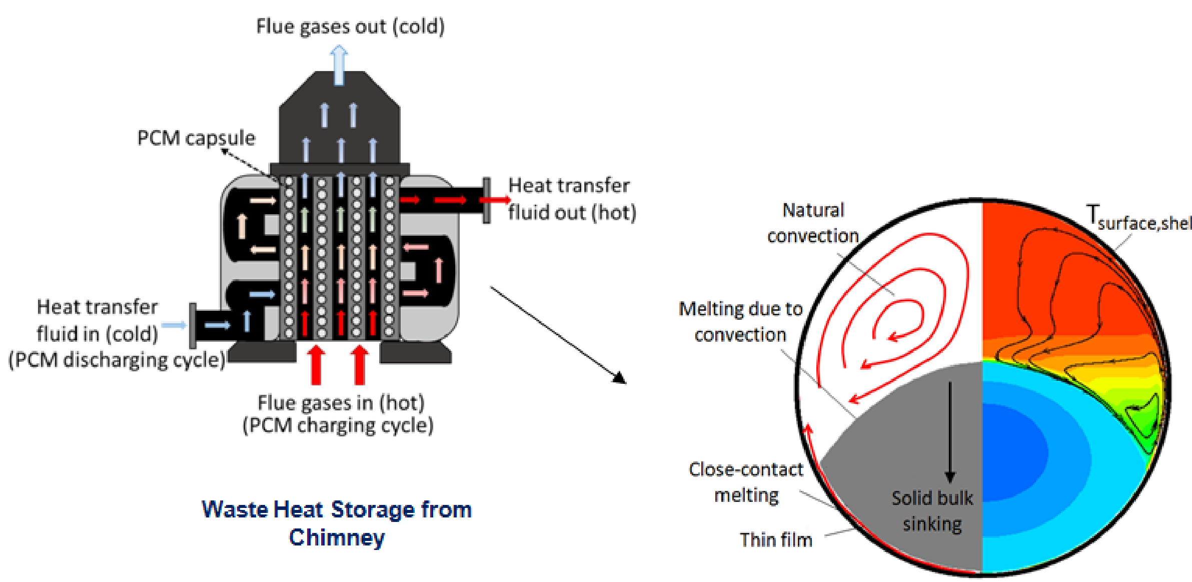

Figure 5: Fast waste heat recovery from chimney using close-contact charging of nano-enhanced phase change material composite. The physical phenomena of PCM melting during discharging in one of the spherical capsules is shown in the right image.